RESEARCH DEPARTMENT

The Measurement of the Vertical Polar Diagram of Medium-Wave Transmitting Aerials Summary of Two Methods.

Report No. K.099

Serial No. 1954/30

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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R.A. Rowden, B.Sc.(Eng.), D.I.C., A.M.I.E.E.
L.F. Tagholm, A.M.I.E.E.
D.E. Susans.
D.N. Cudlip.

W. Proctor Wilson

(W. Proctor Wilson)

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SUMMARY OF TWO METHODS

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SUMMARY.

This report describes two methods for the measurement of the vertical polar diagrams of medium-wave aerials. A practical example of the application of both the methods is given as the results of measurements made on the high mast radiator at Brookman's Park on 877 kc/s.

One of the methods employs a direct measurement system in which field strength equipment is moved slowly over the aerial by means of a helicopter. In the second method the vertical polar diagram of the aerial is compared with that of a standard aerial of known vertical polar diagram by means of pulse transmissions reflected from the ionosphere.

Fairly good agreement was observed between the results obtained by the two methods and the calculated vertical polar diagram. It is concluded that either method may be used, but the pulse method is to be preferred on the grounds of economy and convenience.

1. THE HELICOPTER METHOD.

For this method of direct measurement, a helicopter was chosen as the only practical method of conveying the measuring equipment sufficiently slowly over the aerial. In order to reduce the amount of equipment in the helicopter, and to avoid the necessity of carrying an engineer and recording meter, a radio link telemetering system was developed for conveying the information from the aircraft to the recording equipment installed on the ground.

A loop aerial is mounted about 7 ft (2 m) from the side of the helicopter, ground tests having shown that at this distance the helicopter has no effect on the pick-up properties of the loop. The output from the loop is fed to a unit which produces an audio frequency dependent upon the strength of the signal picked up by the loop. This audio signal is transmitted to the ground by a 93·5 Mc/s radio link and fed into a recording frequency meter. The whole system is normally calibrated immediately before a measurement.

Fig. 1 shows the external arrangement of the loop aerial and the VHF transmitting dipole, and Fig. 2 is a block schematic of the air and ground equipment.

The helicopter is navigated to fly a straight course over the aerial at a height of 10 000 ft (8000 m), the run extending for seven to eight miles (11 to 13 km) on either side of the aerial, thus enabling the measurement of the polar diagram to an elevation of 15°. A vertical drop to the ground may be performed on one or more runs in order to complete the polar diagram. In order to obtain accuracy of reading, particularly at large angles of elevation, extremely careful navigation of the helicopter is required. It was found during early experiments that only by the skilled use of the Decca navigation system could the desired degree of navigational accuracy be obtained. To give an accurate correlation of position and field strength, the navigator is provided with a push button switch, enabling him to vary the audio frequency momentarily, at predetermined Decca lattice points, and thus mark the recording chart indicating the position of the helicopter.

2. THE PULSE METHOD.

With this method, the polar diagram of the aerial to be measured is compared with that of a standard aerial of known polar diagram. This standard aerial normally consists of a low T aerial (i.e. less than $0{\cdot}1\lambda$ effective height) erected a short distance from the aerial whose polar diagram is to be determined, but not so close as to cause distortion of the polar diagrams of either or both aerials due to re-radiation.

The polar diagrams are compared by transmitting short R.F. pulses alternately from the two aerials. These pulses are received at a number of points along a radial in the required horizontal direction from the transmitter. At the receiving points, the pulses are displayed on a cathode ray tube with a time base synchronised to the pulses, thus enabling relative amplitude measurements to be made on the two ground waves and the two sets of echoes from the ionosphere. Since range markers are also incorporated in the display the path difference between the ground wave and each echo can be found, and since the distance between transmitter and receiver is known, the angle of elevation appropriate to the trajectory of any particular echo can be calculated.

The measurement of relative ground wave and echo amplitudes is simplified by feeding the incoming signal through a pair of calibrated attenuators and then into an electronic switch. The switch effectively feeds the set of pulses from one aerial through one attenuator and the set from the other through the second attenuator, thus enabling the gain for the two sets of signals to be varied independently. One of these attenuators is normally used to set the ground waves to equal amplitudes and the other is used to determine the relative amplitudes of a given echo. It has been found better practice to set the echoes to equal amplitudes by the attenuators than to try to estimate the relative amplitudes directly from the spot deflection of the cathode ray oscilloscope, since the echoes fade to some extent independently of one another. When the relative amplitude of the echoes for a given path difference and, therefore, angle from the transmitter has been found, the relative polar diagrams for this angle can be deduced and if repeated for a number of different receiving points the unknown vertical polar diagram can be plotted. It is normally only practicable to measure from a high angle of elevation down to an elevation of about 40°, since this requires measurements at distances of 150 miles (240 km) from the

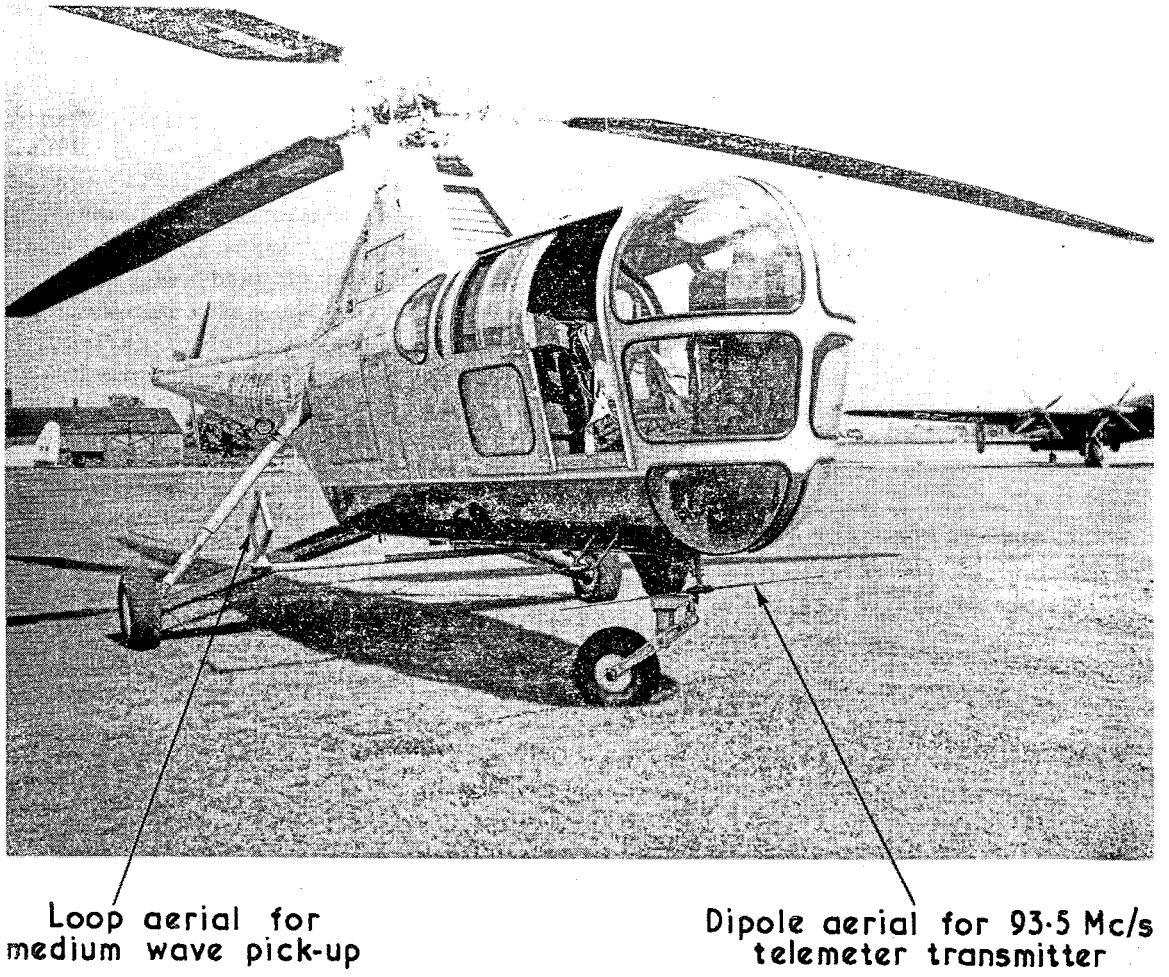
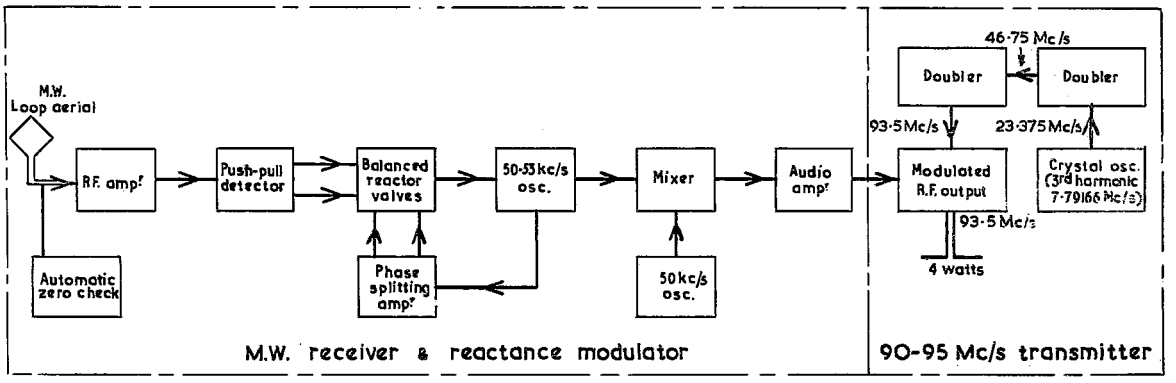


Fig. 1 - Arrangement of aerials on helicopter



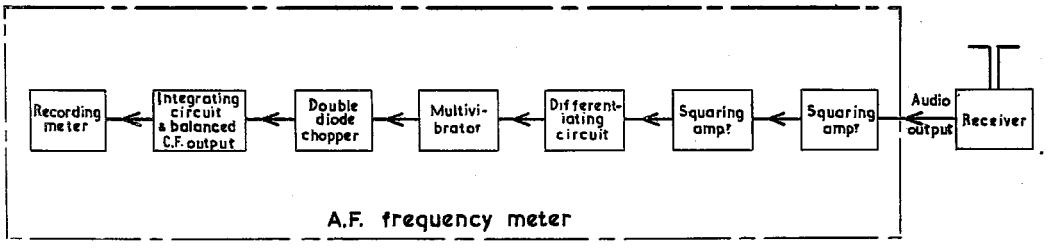


Fig. 2 - Block diagram of helicopter equipment

transmitter where the ground wave will be very weak. This limitation is acceptable as in most practical cases the greatest interest lies in angles of about 60° of elevation around which angle most transmitters are required to limit upward radiation to minimise the fading at the fringe of the service area.

In practice, there are normally observed a considerable number of echoes of different ranges in addition to the normal single hop E and F layer echoes. These are apparently due to irregularities in the ionosphere and if used can cause considerable error in the calculation of the angle at which the radiation left the transmitter, since the layer is assumed to be horizontal at the point of reflection, giving a symmetrical path in the vertical plane. For this reason, the only echoes used for actual amplitude comparisons are the single hop E and F echoes with the shortest path differences.

3. THE RELATIVE MERITS OF THE TWO SYSTEMS.

The helicopter method of measurement has the following advantages:

a. It provides a direct measurement of the complete vertical polar diagram in the directions flown.

b. It does not require a standard transmitting aerial of known polar diagram.

c. The measurements are made in quick succession with only two hours of flying time required to cover the polar diagram in four directions.

d. No modifications are required at the transmitter and measurements are taken during normal programme hours.

The principal disadvantages of this method are:

a. The limited ceiling of the helicopter which means that with the relatively long wavelengths involved, the receiving equipment approaches to within a few wavelengths of the aerial. It is thus sufficiently close for local ground reflections, such as those from buildings and other masts, to have a different effect on the polar diagram to that which they would have if the measurement could have been made at a greater distance.

b. It requires good weather for the navigation which must be very accurate (i.e. ± 20 ft (6 m) over the aerial). This navigational accuracy is difficult to obtain except in certain areas of the country where a navigation system of high accuracy exists. (In the case of the Brookman's Park measurements, the area was one where, fortuitously, exceptionally high accuracy was obtainable from the Decca Navigator System.)

c. The cost of this method is relatively high.

The pulse method of measurement has the following advantages:

a. Ease of measurement once the transmitting and receiving apparatus has been constructed. There are no delays due to weather and navigational

difficulties such as are experienced with the helicopter.

b. Much lower cost per polar diagram as compared with the helicopter method.

c. The polar diagram is measured as it would appear to an observer at a large distance and this includes the seasonal effects of local ground constants and ground configuration in the neighbourhood of the transmitting aerial.

The main disadvantages of this method are:

a. Measurements must be made at intervals of 10 - 15 km up to 250 km from the transmitter, which is not always practicable if the transmitter is using a long sea path to increase its service area, e.g. Start Point and Burghead.

b. It is not normally possible to measure the polar diagram at angles of elevation below 40°.

c. It requires a standard transmitter aerial of known polar diagram, normally a low T aerial.

4. THE EQUIPMENT FOR THE HELICOPTER METHOD.

The equipment in the helicopter consists of:

a. A screened loop aerial about 1 sq. ft in area mounted externally 7 ft (2·1 m) to the side of the helicopter. (See Fig. 1)

b. A medium wave receiver and reactance modulator unit.

c. A 93·5 Mc/s 4-watt transmitter and half-wave dipole for this transmitter. (See Fig. 1)

On the ground, the equipment consists of:

a. A 93·5 Mc/s receiver and aerial.

b. An audio frequency meter.

c. A recording milliammeter.

Fig. 2 is a block schematic of the complete equipment. The power supplies for the units in the aircraft are normally 24V driven rotary converters for the H.T. supplies. The audio frequency meter is supplied from an internal mains power pack, but all three units may use an external power pack if required.

The entire equipment is calibrated before use for absolute field strength and for the input/output law of the system.

5. THE EQUIPMENT FOR THE PULSE METHOD.

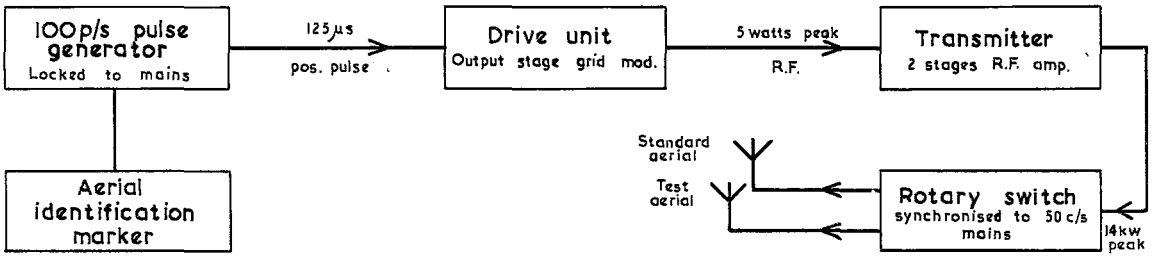


Fig. 3 - Transmitter. Pulse System.

A block diagram of the equipment at the transmitter for the pulse method is shown in Fig. 3. It consists of:

a. A pulse generator giving 125 μsec pulses at a P.R.F. of 100 p/s.

b. A drive unit.

c. A pulse transmitter giving pulses of 14 kW peak power output.

d. A synchronous rotary switch and pulse monitor.

e. A standard aerial giving a known vertical polar diagram.

This apparatus must be conveniently assembled in proximity to the aerial under test.

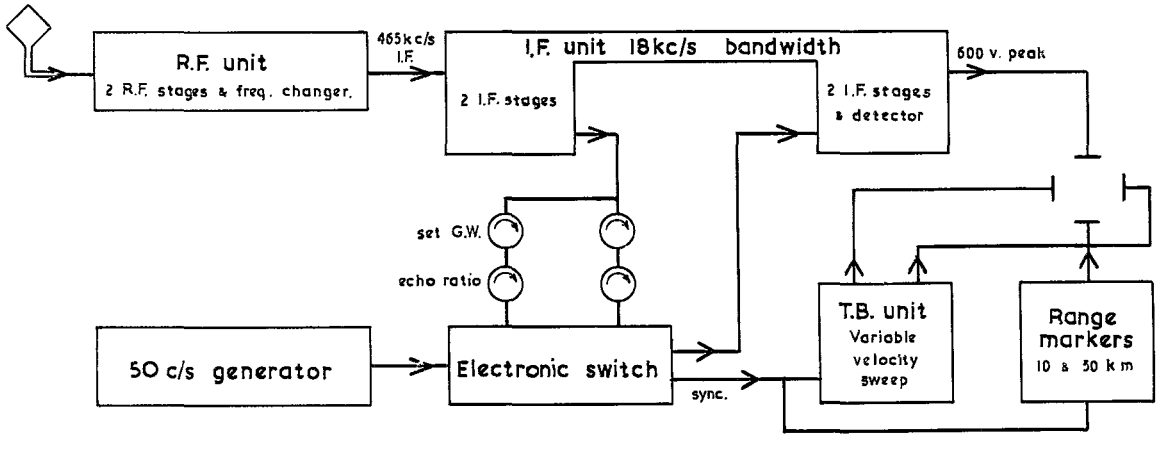


Fig. 4 - Receiver and Display Units. Pulse System.

Fig. 4 is a block diagram of the equipment at the receiving point, which consists of:

f. A receiving aerial, normally a loop.

g. A pulse receiver.

h. An electronic switch with calibrated attenuators.

i. 50 c/s oscillator.

j. A time base and range marker unit.

k. A cathode ray tube with power supplies.

The standard transmitting aerial normally consists of a T aerial slung between masts of about 70 ft height (21 m). For medium wave band working an aerial of these dimensions will be short in relation to the wave-length and will, therefore, closely follow a cosine law. The matching and feeder lengths of both this and the aerial under test must be adjusted to give the correct termination for minimum re-radiation while the other aerial is transmitting.

The receiving aerial may be any aerial but a loop is normally used since this has good pick-up from high angles. It also enables simple D.F. measurements to be made as a check that the echoes are arriving from about the same azimuth as the ground wave and so helps the observer to ignore some of the spurious echoes.

The receiver may be a standard type of medium wave receiver but it is advantageous to use a special pulse receiver with adequate I.F. amplification and high level detection for direct coupling to the C.R.T. plates. Such a receiver may be made with very short time constants to avoid grid current and other troubles introduced by the heavy overload produced by the ground wave while examining weak echoes. Near the transmitter these echoes are frequently less than 1/1000 of the amplitude of the ground wave and if they are to be seen at a reasonable amplitude there is a risk of overloading by the ground wave pulse.

The pulse receiver used for the tests described in this report was based on an original design by Mr. Piggott of the Radio Research Station to whom we are indebted.

Details of the apparatus used for these experiments are given in the Appendix.

6. RESULTS OF MEASUREMENTS.

Both the helicopter and the pulse method were used to measure experimentally the vertical polar diagram of the Brookman's Park mast radiation, at that time working on a frequency of 877 kc/s.

For the helicopter method the aircraft was flown at a constant height of 10 000 ft (3000 m) across the mast radiator in approximately north-south and east-west directions——the actual directions being made to coincide with Decca navigation lines. Two runs were made in each direction with the mast in its normal condition i.e. with a

loading coil of $2\frac{1}{3}$ turns at the break in the mast.

For the pulse measurements the standard aerial used was a low T aerial between 70 ft (21 m) masts and was set up about 550 ft (170 m) away from the high mast radiator. The transmitter and rotary switch were installed in the Aerial Transformer House at the base of the mast and connection was made to the low T aerial by a coaxial cable. Measurements were made in approximately northerly and westerly directions to coincide with the helicopter runs. The distances from the transmitter at which measurements were made were 7 - 150 miles (11 - 240 km) to the north and 7 - 96 miles (11 - 155 km) to the west; these distances gave minimum angles of elevation of 42·5° and 54° respectively. Measurements were taken on first hop E and F layer echoes only.

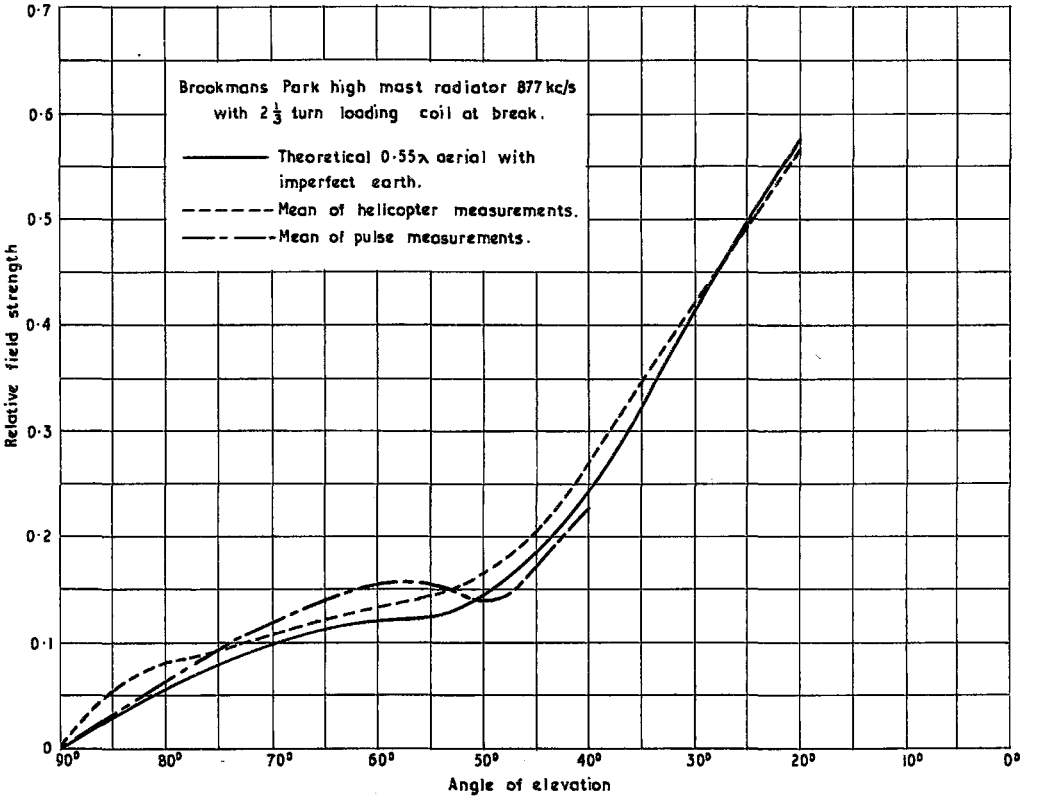


Fig. 5 - Vertical Radiation Pattern.

Both types of measurement involved a very considerable expenditure of time and effort and the final results are presented in the form of curves shown in Fig. 5. Fig. 5 shows also a theoretical curve for a 0·55λ aerial and an imperfect earth.

7. CONCLUSIONS.

It was found that both methods of measurement give results which are in close agreement with the theoretical curve. There was, however, much less variation in individual measurements when using the pulse method. This is believed to be due to local ground reflections having a greater effect on the helicopter readings. The pulse method is easier to apply in most conditions and is the more satisfactory method for normal requirements. Improved equipment is being developed for the pulse method which it is intended should be used for future measurements on other existing B.B.C. mast radiators and other medium frequency transmitting aerials.

APPENDIX

DETAILS OF APPARATUS USED FOR THE HELICOPTER METHOD

The loop aerial is a four turn screened loop of about 0·1 sq. m in area, and is connected to the medium wave receiver and reactance modulator unit by a screened lead. The unit, Fig. 6, consists of one stage of H.F. amplification (V1) followed by a push-pull detector V2 the D.C. output of which is fed into the control grids of the reactor valves V3 and V4. V5 is a 50 kc/s oscillator whose output is fed to a phase splitting valve V6 which in turn feeds two phase shifting networks to give outputs at $\pm 90^{\circ}$ from that in the oscillator circuit. These two outputs are fed one into each of the reactor valves V3 and V4. When there is no signal input, these valves are balanced and there is no output at the common anode circuit. When a signal is applied to the input the valves are unbalanced, thus giving an output which varies in amplitude with the signal input and in quadrature with the oscillator voltage. This output is applied across the inductance of the tuned circuit, and hence varies the frequency of the oscillator. V8 is a similar oscillator of fixed frequency and the two oscillator outputs are fed into a mixer V7. The audio beat is filtered out and amplified by V9.

The frequencies of the oscillators are set so that with no medium-wave input signal the beat frequency is approximately 200 c/s and with maximum input signal the beat frequency is 3·5 kc/s. The minimum frequency of 200 c/s was chosen so that in the event of one of the oscillators drifting with respect to the other, the amount and direction of this drift can be observed by the change in this frequency and may thus be corrected. If the minimum frequency was zero the direction of the drift could not be determined and hence could not be corrected. In order to have a frequent check on this zero setting the input from the loop aerial is short-circuited for 2 sec every 30 sec by a relay operated by V10.

The audio output from this unit is fed into a crystal controlled VHF transmitter. This transmitter consists of a crystal oscillating at its third harmonic followed by two doublers and a grid modulated push-pull power output stage giving an output of about 4-watts R.F. The transmitting aerial consists of a half-wave dipole mounted horizontally under the aircraft. (See Fig. 1.)

On the ground, the audio output from a normal 93·5 Mc/s receiver is fed into an audio frequency meter (Fig. 7). This consists of two pentode squaring stages V1, V2 followed by a flip-flop circuit V3, V4 whose output pulse may be one of two lengths depending on the range. These pulses are chopped to a constant amplitude of 70V by a double diode V6 and are then integrated and fed into a cathode follower V7 which is connected to one terminal of the recording milliammeter. The other side of the milliammeter is connected to the output of a second cathode follower V8 whose grid is connected to a variable positive potential and is in fact an "adjust zero" control, which allows the 200 c/s "zero" frequency to be subtracted automatically.

DETAILS OF APPARATUS USED FOR THE PULSE METHOD

TRANSMITTING EQUIPMENT

a. The Pulse Generator.

The pulse generator produces 125 μsec positive going pulses of 70V peak amplitude with a repetition rate of 100 p/s. Provision is also made for a repetition rate of 50 p/s and for varying the duration of the pulse from 30 to 6000 μsec. In order to identify the particular aerial in use a marker is incorporated which removes alternate pulses for three seconds every half-minute; this will remove all pulses transmitted from one aerial for the duration of the marker.

The first valve V1, (Fig. 8) is a pentode squaring stage fed from the secondary of the mains transformer. The square wave output from this stage is fed into a phase reversing amplifier V2. This valve has approximately 10V cathode bias which is sufficient to cut off its anode current when its suppressor grid is connected to ground via the marker relay. The square wave output from this stage and an equal amplitude portion of that from V1 anode are fed via differentiating circuits and separate diodes V3 to give short negative pulses into the grid of V4 with a repetition rate of 100 p/s. When a P.R.F. of 50 p/s is required, the square waves from V1 anode are omitted by opening the switch S. The large amplitude positive going pulses at the anode of V4 are D.C. restored negative going from earth by a diode V5A. These long negative pulses are then passed through a variable time constant CR to give a negative going exponential waveform at the grid of V6. The waveform at V6 anode is an approximately square pulse of variable duration depending upon the value of the time constant and the potential to which the grid of V6 is returned. The pulse is further shaped by V7 and phase reversed by an anode follower V8, the positive pulse from the anode of this valve feeding the output terminals.

The marker valve V9 is a self-running Miller time base circuit; it has a relay in series with a pre-set resistor as the anode load. This resistor is used to set the marker duration in conjunction with the grid circuit time constants, to a half minute. The H.T. supply is stabilised by a neon stabiliser V10.

b. The Drive Unit.

The R.F. drive unit is a standard B.B.C. drive, type CP-27, modified for pulse operation. The modification consists of a circuit to bias off the output valves on their control grids except for the duration of the required output pulse. The drive unit covers a frequency range of 500 - 1500 kc/s as a variable frequency oscillator or it can be used for spot frequencies with a crystal. The peak power output is five watts.

Other types of R.F. drive unit are, of course, readily adaptable for the same purpose.

c. The Pulse Transmitter.

The pulse transmitter is designed to operate anywhere in the band 500 - 1500 kc/s and gives 14 kW peak output on 125 μsec pulses at a P.R.F. of 100 p/s.

The circuit, Fig. 9(a), consists of two stages of class C amplification with the necessary power supplies and safety circuits. The first stage consists of a pentode amplifier V1 with a step-up tuned circuit in its grid and an anode tuned circuit common with the grid of the output stage. This output stage consists of a pair of tetrodes V2 and V3 in parallel, their anode tuned circuit being in a separate unit. In this tuned circuit both the inductance and capacity are made variable in order to maintain optimum conditions. The output circuit is closely coupled to this tuned circuit and the turns on this coil may be varied in order to change the coupling. Both stages in the transmitter are normally biassed beyond cut-off and the R.F. input pulse causes them to draw current. The bias for the output stage is stabilised at -750V by neon stabilisers V4-8.

The duty factor of the input pulses is measured by a duty factor meter, Fig. 9(b), and if it is too high it will trip the transmitter H.T. This circuit consists of a detector V11A and pulse amplifier V12 giving positive pulses out. These pulses are fed into a D.C. restorer V11B and cathode follower V13. The cathode circuit of this valve integrates the pulses and the mean cathode current is indicated on a meter, bias being applied to the cathode to keep it cut off under no signal conditions. Further cathode followers V14, V15, V16 are used to operate a relay G if either the duty factor exceeds a pre-set value (2% approximately) or if either of the two bias supplies fail. The relay if operated opens the interlock circuit and removes the H.T. and E.H.T. supplies, similarly overload in either of the main amplifying stages will also open the interlock circuit.

The first stage is fitted with a C.R.T. monitor on which both grid and anode waveforms are displayed in order to assist tuning.

The power pack gives three H.T. supplies of 600V, 1200V and 10kV variable. These supplies are controlled by relays which give the correct switching sequence at suitable time intervals.

d. The Synchronous Switch and Pulse Monitor.

A three phase synchronous motor drives a commutator switch which alternately shorts or connects the feeders to the aerial under test or to the standard aerial. The output brushes are mounted on a rotatable housing so that each aerial receives the pulse at the right instant. A second commutator with a very small contact angle is used in conjunction with the pulse from the pulse generator and the pulse monitor for setting the brushes; dummy loads and output voltage sampling resistors are also provided.

The output pulses across these sampling resistors are fed into the pulse monitor which consists of a cathode ray tube with power supplies and a 50 cycle time base normally synchronised to the mains. Amplifiers for these pulses are also fitted and provision is made for use with an aerial input instead of a direct input. The monitor is used as a check on the power being fed into each feeder and with the D.C. pulse input to set up the commutator phase.

RECEIVING EQUIPMENT

a. The Pulse Receiver.

The pulse receiver has a R.F. unit consisting of a grounded grid input stage followed by a R.F. amplifier and frequency changer. An input attenuator is provided so that the receiver could be used close to the transmitter for checking the shape and duration of the pulse. A continuously variable capacity attenuator on the output allows a constant level to be fed to the I.F. amplification, the last being push-pull, followed by a voltage doubling detector giving an output of approximately 600V peak. The I.F. chain is broken after the first two stages in order to insert the attenuator unit and electronic switch. An audio amplifier is also provided for monitoring.

b. The Attenuator Unit and Electronic Switch.

The attenuator unit consists of two simple attenuators with their inputs in parallel. Both attenuators are calibrated for measuring the echo amplitude through an additional uncalibrated attenuator in one arm which is used initially at each observation location to set the ground waves to equal amplitudes. The outputs from the two attenuators are fed into the control grids of the valves V1, V2, (Fig. 10), which form the electronic switch. These valves have a common anode load and the output across this load is fed into the final I.F. stages of the receiver. Square waves are applied to the suppressor grids of these valves so that only one is conducting at a time, thus switching between the output of the two attenuators. The square waves are produced by a multivibrator V4 which is driven by the differentiated output of a swuaring stage V3. The input to this squaring stage consists of either a phase shifted 50 c/s output from the mains, or an external 50 c/s input. The mains synchronisation is used when the supply is locked to that at the transmitter site. The result of this controlled synchronous switching is that an attenuation will be effective only on the pulses received from the aerial under test and the other attenuator will control only the pulses received from the standard aerial.

c. The 50 c/s Oscillator.

This unit, Fig. 11, is a simple 50 c/s phase shift oscillator held in phase by a manual control.

The 50 c/s oscillator consists of a simple phase shift oscillator V2A, V2B, V3A feeding an amplifier V3B. The frequency of this oscillator is varied over a small range by a fine control resistance and this is used to hold the output in the required phase.

The H.T. supply is stabilised by a neon stabiliser V1.

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d. The Time Base and Range Marker Unit.

This unit, Fig. 12, produces a time base of variable sweep speed and, locked to the electronic switch operation, it also produces range markers at a frequency equivalent to 10 km and 50 km to enable path difference measurements to be made. A detector and pulse amplifier are included to enable normal receivers with a low I.F. output voltage to be used with the equipment if desired.

A negative going pulse input from the electronic switch, coinciding with the start of the square waves in this switch, is fed via a diode V1A into a multivibrator V5. This valve produces short negative going pulses. These pulses are used to reset the markers at the start of each time base and are also fed on to the screen of V6, the time base valve, to initiate the flyback. The time base sweep starts at the end of the negative pulse and the sweep speed is determined by the value of the grid resistor and the resultant potential to which it is returned. The time base from V6 is fed into a floating paraphase amplifier V7 to provide a push-pull output for the X plates of the C.R.T. The sawtooth time base is also differentiated and fed into V2B where it is squared and used as a pulse to black out the flyback and waiting time at the end of the sweep.

The range markers are obtained from two blocking oscillator valves V3, V4. The first of these operates at 30 kc/s and gives 10 km markers, and is held to this frequency by a ringing tuned circuit in the grid, the oscillator being adjusted for maximum voltage across this circuit. These markers are used to trigger V4 which operates as a "divide by five" stage giving 50 km markers. The markers may be selected as required and are then fed into amplifiers V8, V10 and thence on one of the Y plates of the double beam C.R.T. In order to synchronise the markers with the time base, the two oscillator valves V3, V4 have their anode current cut off during the time base flyback by the negative pulse from the multivibrator which is applied to the suppressors of these valves thus permitting the oscillations to die out and be re-started at the commencement of each sweep.

In addition to these circuits, a 465 kc/s detector V9 and pulse amplifier V8, V11 are provided, for use with a receiver having only a low level I.F. output. Provision is also made to operate the time base at a variable frequency to enable the unit to be used for fault finding on other parts of the equipment.

e. The Cathode Ray Tube Unit.

This unit is a Cossor double beam cathode ray oscilloscope which has been modified by the inclusion of a R.F. E.H.T. unit.

The receiving equipment may be run from a 230V 50 c/s supply, but when used in a vehicle it is more convenient to use a locally generated supply such as the 230V 1200 - 2000 c/s alternator driven by the vehicle engine fitted to the B.B.C. Field Strength Vans.

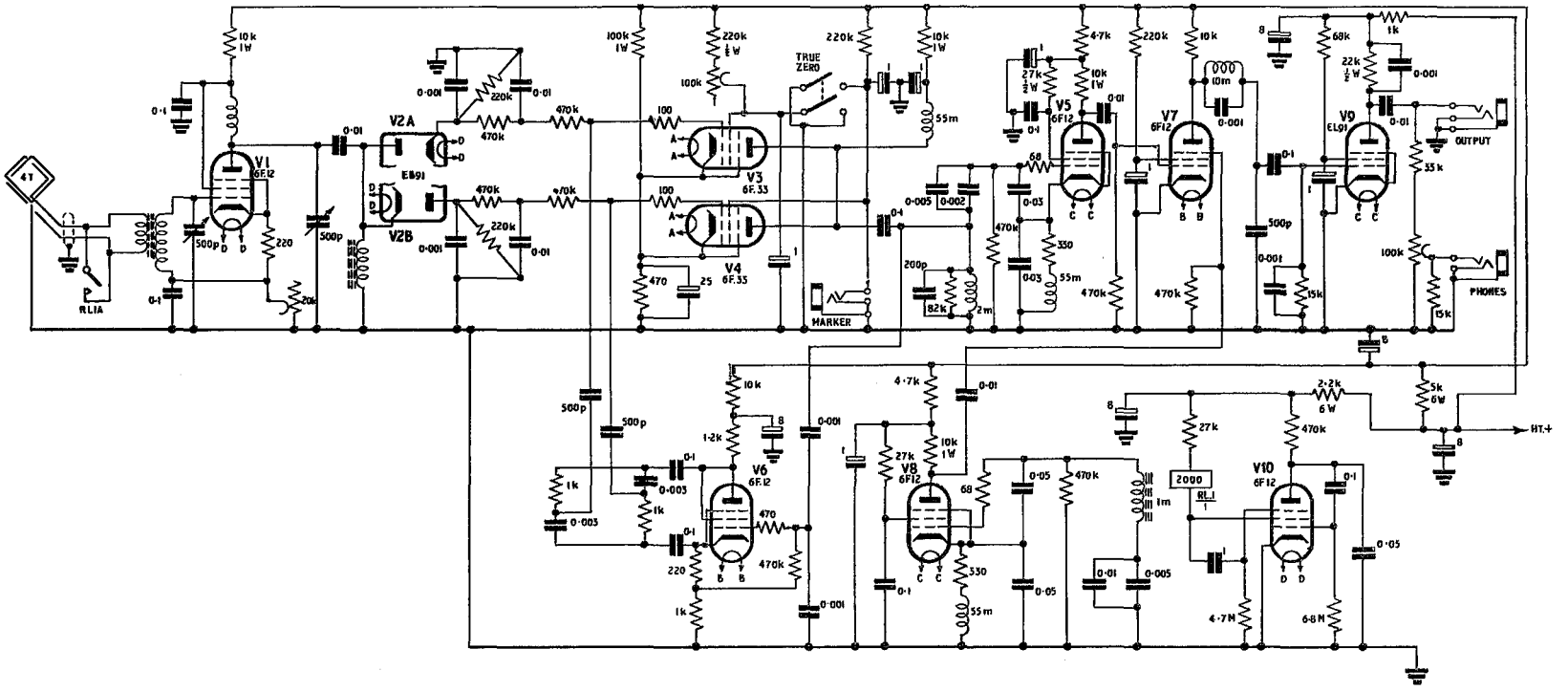


Fig. 6 - M.W. receiver and reactance modulator unit

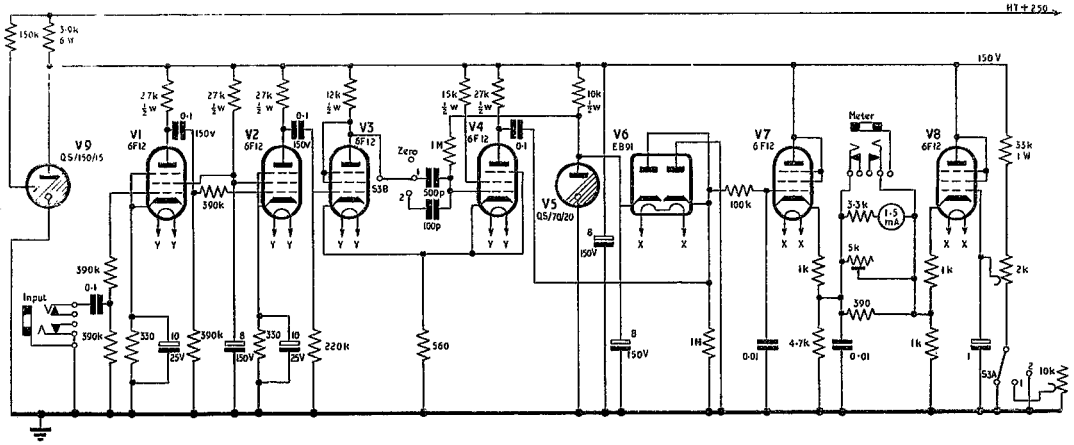


Fig. 7 - A.F. Frequency meter

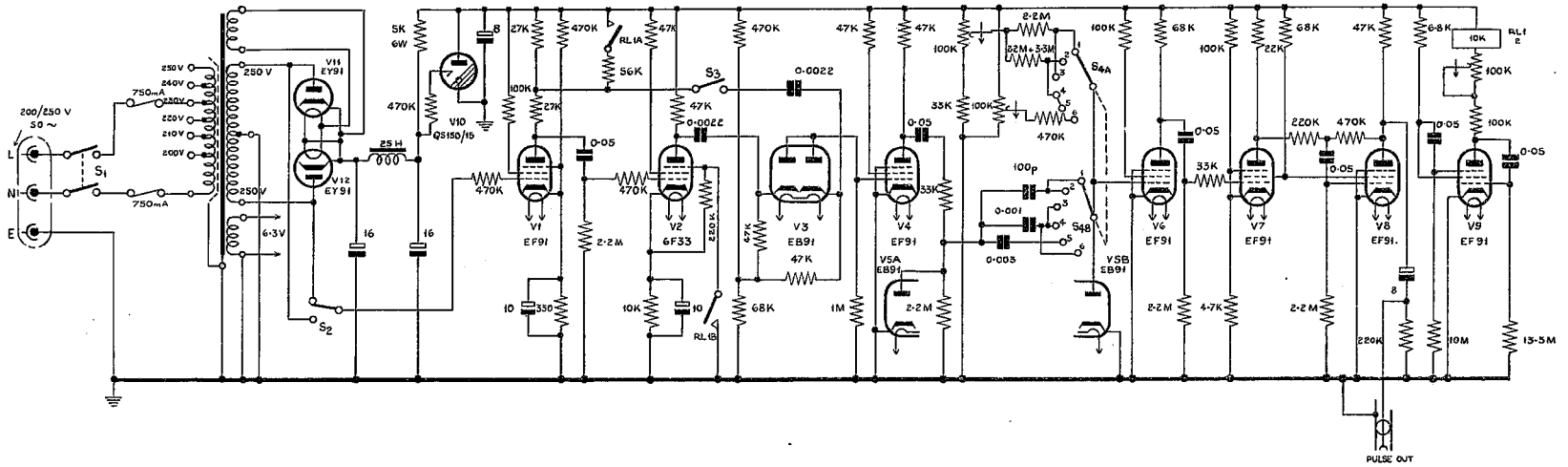


Fig. 8 - Pulse generator

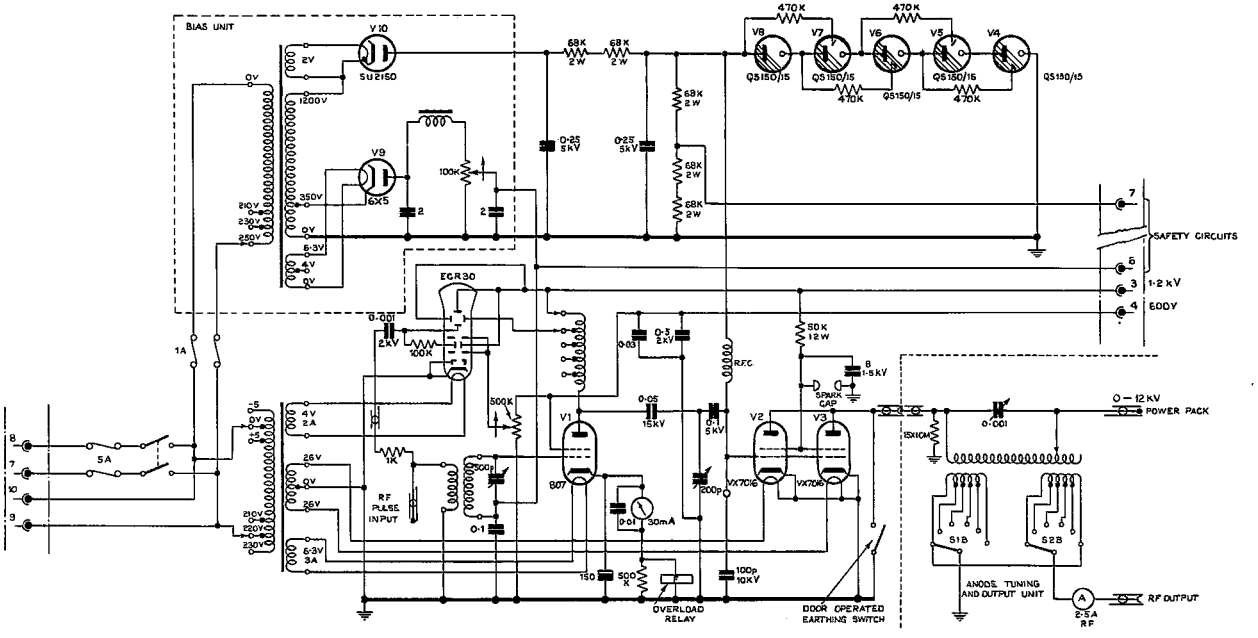


Fig. 9a - Pulse transmitter. R.F. unit

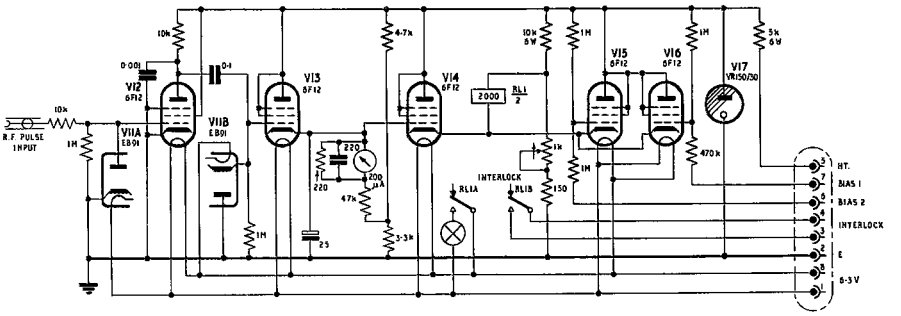


Fig. 9b - Pulse transmitter. Duty factor meter

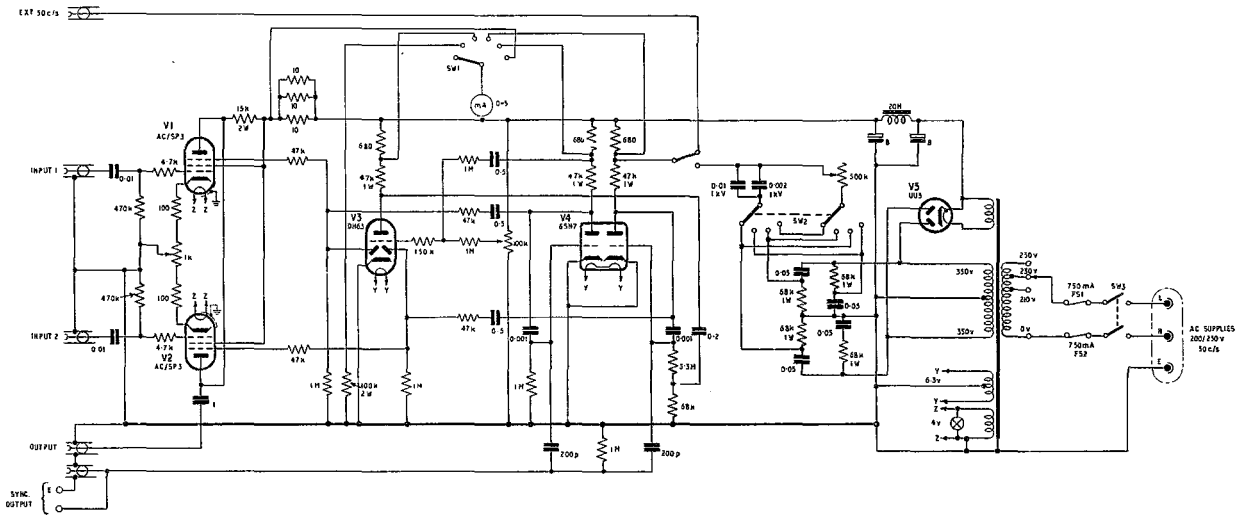


Fig. 10 - Electronic switch

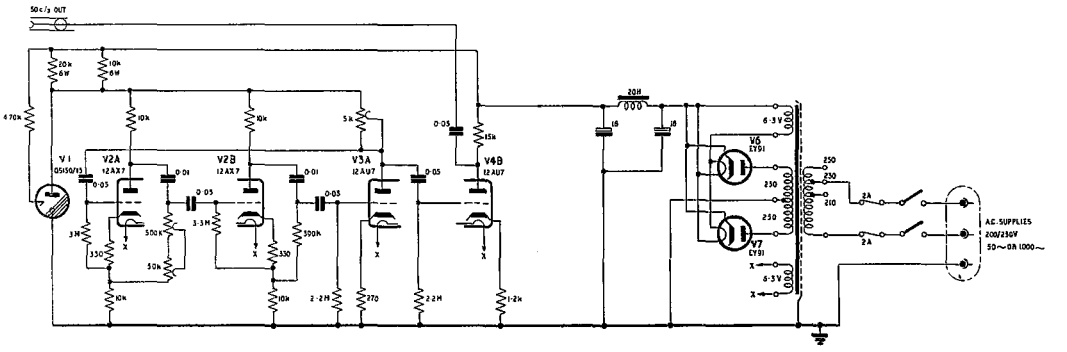


Fig. 11 - 50 c/s oscillator

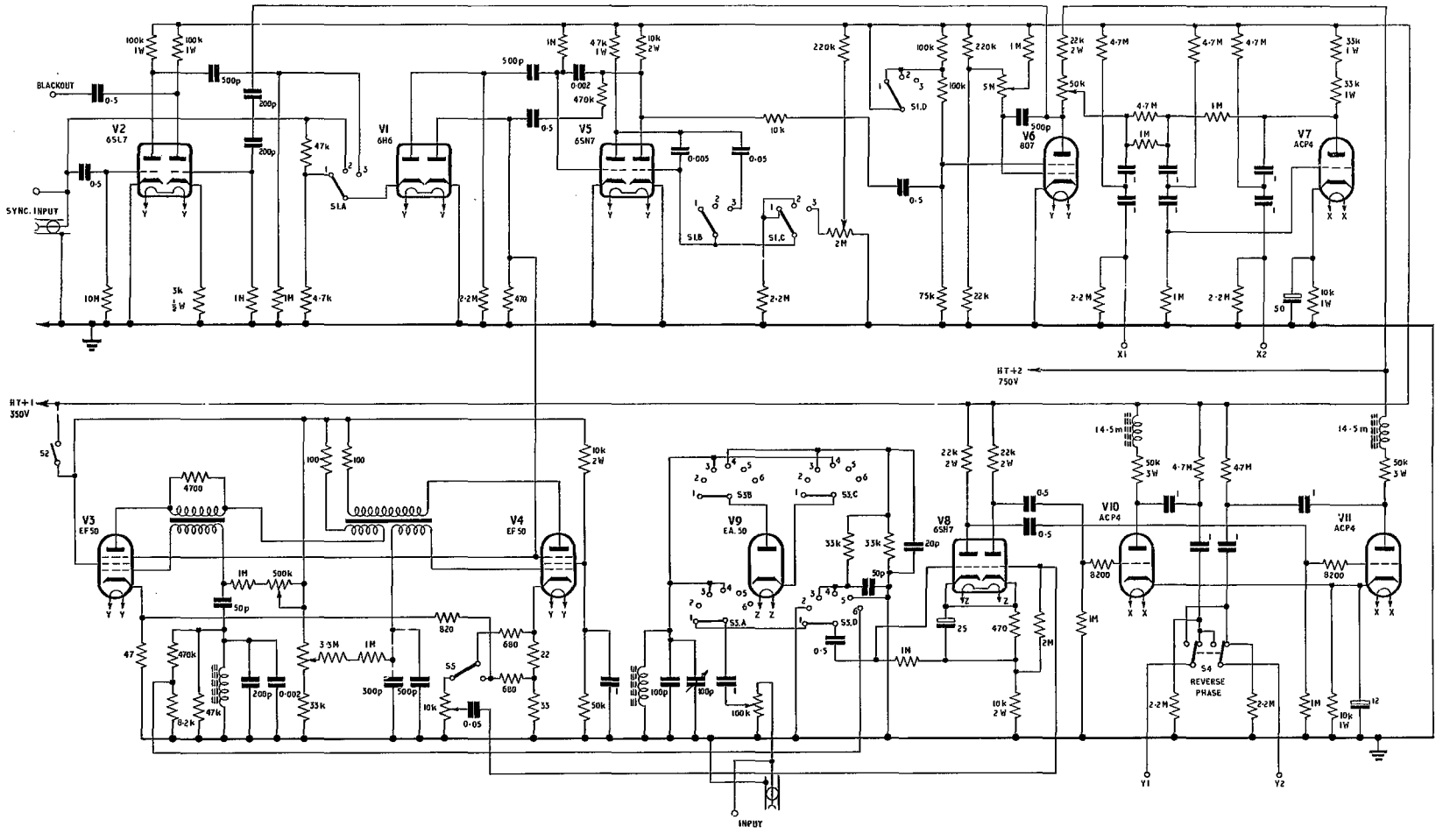


Fig. 12 - Time base and range marker unit